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CLASSIFICATION OF THE DEFORESTED AREA IN CENTRAL RONDÔNIA USING TM IMAGERY

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Abstract: Total deforested area by August 1995 was estimated by digital classification of one Landsat Thematic Mapper image (Path/Row=231/067) covering a region of old settlement projects in Rondônia, western Brazilian Amazônia. Deforested area was estimated within the territories of the *municípios* of Ariquemes, Cacaulândia, Governador Jorge Teixeira, Jamari, Jarú, Ji-Paraná, Machadinho d'Oeste, Ministro Andreazza, Ouro Preto do Oeste, Presidente Médici, Rio Crespo, Theobroma, Vale do Paraíso, in Rondônia, and Aripuanã, in Mato Grosso, and also for regions within 12.5 km from federal road BR-364. Total deforested area was estimated to be 1.2 million hectares by August 1995 or 35% of the area of study. The territories of Cacaulândia, Jarú, Ministro Andreazza, Ouro Preto do Oeste, Presidente Médici and Vale do Paraíso were deforested by more than 50%, inside the study area, while areas within 12.5 km from BR-364 were deforested by 80%.

Keywords: Land use dynamics, deforestation, Amazônia

1. Introduction

The forests of Brazilian Amazon have undergone important changes over the past three decades. These changes have resulted in the removal of at least 52 million hectares (ha) of forests by 1996 (INPE 1998), with areas presenting the highest rates of deforestation in the oriental and south-western flanks of the Brazilian Amazon, particularly in the states of Mato Grosso, Pará, and Rondônia (Tardin *et al.* 1980, INPE 1998, Alves *et al*. 1998). Forest removal is at the origin of several environmental impacts on both the global and local scales, including disturbances of the global and regional climate (Gash *et al.* 1996), emissions of CO_2 and other greenhouse gases to the atmosphere (Schimel *et al*. 1996), and soil degradation (Buschbacher *et al.* 1988, de Moraes 1995).

Satellite imagery has helped to improve the mapping of tropical deforestation, particularly in the Brazilian Amazon (Tardin *et al.* 1980; INPE 1989; Alves *et al.* 1992; Skole and Tucker 1993; Chomentowski *et al.* 1994). Satellite data has also been used to evaluate the dynamics and the patterns of land use in deforested areas (Alves and Skole 1996, Alves *et al*. 1998, Frohn *et al*. 1996, Moran *et al.* 1994, Skole *et al.* 1994).

This work presents an analysis of the 1995 total deforested area based on the digital classification of one Landsat Thematic Mapper (TM) image (Path/Row=231/067) covering a region of old settlement projects in Rondônia, western Brazilian Amazônia. Total deforested area was also

estimated for the territories of the *municípios* inside the study area, and for the areas within 12.5 km of federal road BR-364, the major road link between western Amazônia and the rest of Brazil. The major goal of this investigation was to provide data about the extent of forest depletion occurring in the region and to contribute to a better understanding of some of the impacts of deforestation.

2. Study Area

The study area was located in the western Brazilian Amazon, including parts of *municípios* Ariquemes, Cacaulândia, Governador Jorge Teixeira, Jamari, Jarú, Ji-Paraná, Machadinho d'Oeste, Ministro Andreazza, Ouro Preto do Oeste, Presidente Médici, Rio Crespo, Theobroma, and Vale do Paraíso, in the state of Rondônia, and Aripuanã, in the state of Mato Grosso (**Figure 1**). Its boundaries correspond to the area covered by TM scene path/row=231/67, representing a total area of approximately 3.4 million ha.

FIG. 1

Human occupation in the study area has considerably increased during the last three decades, following the building of federal road BR-364 and the development of some of the oldest and largest settlement projects in the state of Rondônia. The deforestation process continues to be intense in the region (Alves *et al*. 1998), arousing the interest in monitoring it.

The BR-364 road bisects the area of study and served as the way of penetration in the region at the time of its colonisation. To the present, the road constitutes the basic link by land between Rondônia and the more populated south of Brazil, serving as the major way to export the region's production, and to bring goods in.

The region includes several of the largest settlements projects organised in the state of Rondônia under the programs of Amazônia colonisation during the 1970's, including Projeto Integrado de Colonização (PIC) Ouro Preto (created in 1970), Projeto de Assentamento Dirigido (PAD) Burareiro (1974), PIC Padre Adolpho Rohl (1975), PAD Marechal Dutra (1978) and PAD Machadinho (1982) (Instituto Nacional de Colonização e Reforma Agrária (INCRA) 1996). These projects occupied more than 2 million ha in the region, where more than 24,000 families were settled from 1970 till 1995 (INCRA 1996). Parts of the region's landscape can be appraised on **Figure 2** and **Figure 4**. The majority of the properties in these settlements is relatively small (25 to 100 ha, INCRA 1996) and is scattered along secondary roads that emerge from the major arteries, creating the typical Rondônia "fish-bone" pattern. The area also includes mid-size (1000 ha) and large (10,000 ha or more) properties.

FIG. 2

FIG. 4

The native vegetation in the region consists of dense tropical forests with mild seasonal characteristics (RADAMBRASIL 1978), a 4 to 6-month dry season and elevations ranging from 100 to 600m. The region also presents several areas covered by non-forest vegetation, associated to the presence of rocky soils.

3. Methods

The TM image Path/Row=231/067, dated 03 August 1995, was read from a CD-ROM and geo-referenced using co-ordinates acquired with differential Global Positioning System equipment. This image was subsequently used as the basis for the geo-referencing of other TM images in the 1985-1995 period, that were used to refine and evaluate the classification results.

The analysis of the data consisted of three major steps:

(1) Characterising the total deforested area in the 03 August 1995 image, including pasture, annual and perennial crops, and secondary vegetation occurring in areas abandoned after clearing;

(2) Determining the deforested area belonging to the *municípios* in the study area;

(3) Determining the deforested area within 12.5 km of the BR-364 road.

The objective of the first step was to generate a map of the deforested area identified in the 03 August 1995 image. A preliminary version of the deforestation map was quickly generated by applying an image-thresholding classifier to the image's mid-infrared channel (TM band 5 - 1.55 - 1.75 μm). The image threshold value was determined by analysing the basic statistics (mean, standard deviation, minimum, and maximum) of different areas, including pastures, annual and perennial crops, fire scars, secondary vegetation, and primary forest. The classification results were filtered to eliminate isolated clusters of less than 9 pixels, and then visually inspected and edited to eliminate classification errors. Most common classification errors included the confusion between secondary vegetation and areas of illuminated forest hills, between pastures and some areas amid primary forest with a large number of rocks, some and undetected burned areas. The visual inspection/error correction procedure was repeated at least once for the entire image, using information collected on the field as well as the available multi-temporal imagery to help in this revision process. The final map was evaluated by calculating the kappa coefficient of agreement (κ) (Fleiss 1981, Hudson and Ramm 1987) with samples taken from the image time-series.

The objective of the second step was to determine the fractions of the deforested land belonging to the *municípios* in the region of study. For this, the classified image was transformed into vector format and the deforested area for each *município* was calculated using a map intersection procedure and a digital map of *municípios* provided by Fundação Instituto Brasileiro de Geografia e Estatística (FIBGE sd).

The objective of the third step was to determine the deforested area within certain distances from the BR-364 road. The distances chosen for this analysis were 2.5, 5, 7.5, 10, and 12.5 kilometres. These distances were chosen considering that settlement areas were originally planned to be traversed by roads every 5 km, with parcels in many settlement projects stretching half this distance. This analysis was done by building corridors (*buffers*) for each of the above distances and performing a

map intersection procedure.

The study area was visited six times in the period from May 1995 to December 1997 to collect data about the types and the dynamics of land use. These visits included localised flights that helped to improve the understanding of land use/land cover types and their response on satellite imagery.

4. Results and discussions

The dimensions of the study area corresponded to 3.411 million hectares, and were actually defined as the common area between TM path/row=231/67 images dated 22 July 1985 and 03 August 1995. This area represented 97% of the area of the 03 August 1995 image, and allowed to establish a reference area for an on-going decade-long study based on a time-series of TM imagery.

The classification results are shown on **Figure 3** and summarised in **Table I**. One million two-hundred thousand hectares or 35.5% of the study area was classified as deforested by 03 August 1995. Total deforestation included different types of land use, such as pastures, and annual and perennial crops and also secondary vegetation.

FIG. 3

TAB. 1

The accuracy of the deforestation estimate is difficult to assess, particularly because of the limited ground information available. Nonetheless, the map on **Figure 3** was partially evaluated within a 500x2,500-pixel area by the kappa coefficient of agreement (κ) (Fleiss 1981, Hudson and Ramm 1987). This area included different types of land covers in parts of the *municípios* of Ariquemes, Cacaulândia, Governador Jorge Teixeira and Jarú. Samples were taken from the 1992, 1994 and 1995 images, including areas of forest in 1995, and pastures, perennial and annual crops, as well as secondary vegetation at different stages of regeneration throughout the image time series. This exercise produced a kappa coefficient $\kappa = 0.979$ ($\sigma^2 = 10^{-6}$, N = 59547), which indicates an excellent agreement between the classification and the test area (Fleiss 1981). This rating corroborates to the perception acquired during the visual inspection/error correction procedure that the final map is reasonably accurate. However, it should be noted that a more complete accuracy assessment of the deforestation map could hardly be done on the basis of the available data. Similarly, the calculation of a confidence interval for the deforested area estimate would require more data and work, and is outside the scope of this paper.

FIG. 3

The estimated deforested area was compared with data reported by the Secretaria de Estado do Desenvolvimento Ambiental (SEDAM) (1997) for the year 1995. To do so, the deforested area map was divided in 1:100.000-scale maps and compared with figures reported in SEDAM (1997) for the same maps (map sheets SC20-X-C-V, SC20-X-C-VI, SC20-Z-A-II, SC20-Z-A-III, and SC20-Z-A-VI were entirely inside the study area and were retained for comparison). This analysis showed that data reported by SEDAM were -1.4%, 21.1%, -5.2%, 7.7%, and -0.2% lower (negative numbers indicate higher SEDAM estimates) than data calculated from the classified image, respectively, for the same map sheets. The large difference detected for sheet SC20-X-C-VI (21.1%) was caused by the use of different dates in the two studies (SEDAM image was dated 03 April 1995, E. Matricardi personal communication 1998), and a 4,000-hectare clearing during the first semester of 1995 in one

single farm. The difference for the other sheets was smaller than 8%, and might be attributed to differences in the methodology and, possibly, in the case of map sheet SC20-Z-A-III, to the growth of deforested area during the period between the two images.

The calculation of the deforested area inside each *município*, showed that approximately 98% of the total deforestation belonged to Rondônia, while 2% occurred in Mato Grosso, as summarised on **Table I**. The table also includes the percent cleared metric (Frohn *et al*. 1996), which was defined as the deforested area relative to the *município* or *buffer* area inside the study region. According to this metric, around half of the territories of Ariquemes, Cacaulândia, Governador Jorge Teixeira and Theobroma were deforested by August 1995. Percent cleared reached even higher values for Vale do Paraíso (2/3), and Jarú and Ouro Preto (3/4).

Table I – Total and deforested area for the *municípios* inside the study area.

Deforested area included all types of land use (pastures, annual and perennial crops) and secondary vegetation. Percent cleared is deforested area relative to *município* area.

Município	**Total area (10^3 ha)**	**Deforested Area (10^3 ha)**	**Percent cleared (%)**
Ariquemes	222.1	101.6	45.8
Cacaulândia	109.3	59.9	54.8
Governador Jorge Teixeira	155.2	732.4	47.2
Jamari	55.5	5.1	9.1
Jarú	241.0	179.1	74.3
Ji-Paraná	663.9	199.5	30.1
Machadinho d'Oeste	647.7	114.3	17.7
Ministro Andreazza	24.4	14.3	58.6
Ouro Preto do Oeste	279.2	206.7	74.0
Presidente Médici	9.2	7.1	76.9
Rio Crespo	219.2	60.3	27.5
Theobroma	218.9	99.8	45.6
Vale do Paraíso	96.3	62.8	65.3
Aripuanã (MT)	469.2	25.9	5.5
Total	**3,411.4**	**1,210.0**	**35.5**

The *municípios* presenting the highest percent cleared values were located in the immediate vicinity of the BR-364 road (**Figure 1**, **Table I**). The relationship between proximity to this road and percent cleared was further analysed and results are reported on **Table II**. Total deforestation within 12.5 km of that road amounted to 318.4 10^3 ha or 26% of the total deforestation in the study area. Approximately 80% of this region had been deforested by August 1995, with percent cleared slightly increasing with the proximity to the road.

FIG. 1

TAB. 1

Percent cleared values were higher than 60% in all *municípios* within 12.5 km of the BR-364 road. All *municípios* in **Table II** presented higher percent cleared values in the vicinity of the road than outside the 12.5 km limit. Particularly, the *município* of Ji-Paraná presented only 30% cleared (**Table I**), but had approximately 90% of its territory cleared within 12.5 km of the road (**Table II**).

TAB. 1

Table II - Percent cleared in regions close to the BR-364 road.

Município	**Percent cleared as a function of the distance (D, km) of the BR-364 road**				
	D < 2.5	**D < 5**	**D < 7.5**	**D < 10**	**D < 12.5**
Ariquemes	79.7	67.4	64.0	63.5	61.0
Cacaulândia	80.1	71.7	68.7	66.1	65.0
Jarú	89.0	86.5	84.2	83.3	82.2
Ji-Paraná	91.9	89.7	90.5	89.6	88.9
Ouro Preto do Oeste	82.9	88.3	85.7	85.5	85.8
Presidente Médici	87.7	83.7	82.1	77.8	80.7
Theobroma	89.0	86.3	84.0	76.8	75.8
Vale do Paraíso	0.0	0.0	0.0	67.8	67.1
Total - BR-364	85.7	83.2	81.3	80.1	79.2

The percent cleared metric presented here is a relatively rough estimate of the remaining forest in the study area. However, it may be noted that these results show deforestation exceeding the 50% limit originally required by federal regulations. Moreover, data derived from Alves *et al.* (1998) study showed high deforestation rates in the area, with rates greater than 60,000 ha yr^{-1} in the 1991-1994 period. Such rates represented 5% of the total deforested area by 1995, indicating that the pressure for expanding the deforestation process to nearby areas may be inducing high deforestation rates, as forested areas diminish in the areas of older settlements.

5. Conclusions

This work reported data on total deforested area in a region of Brazilian Amazônia where the deforestation process has been intense in the last three decades. It also showed that deforestation patterns existing in the region has lead to increases in deforested area beyond the limits established by federal regulations.

This continued process of forest removal is possibly happening in other areas of the Amazon. The use of remote sensing and spatial analysis techniques can help identify such processes and contribute to a better understanding of the processes occurring in the Amazonian region.

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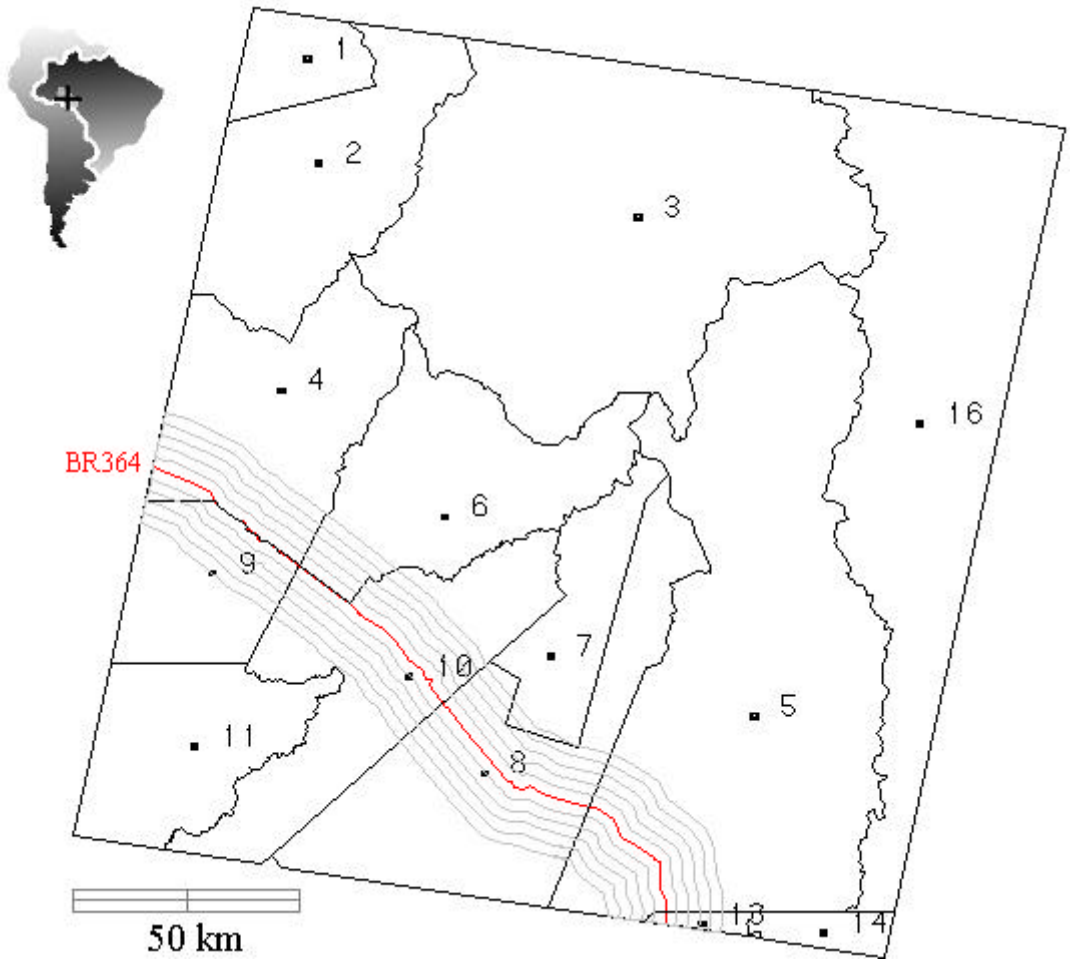

Figure 1 - Location of the area of study and its *municípios*: (1) Jamari, (2) Rio Crespo, (3) Machadinho d'Oeste, (4) Ariquemes, (5) Ji-Paraná, (6) Theobroma, (7) Vale do Paraíso, (8) Ouro Preto do Oeste, (9) Cacaulândia, (10) Jarú, (11) Governador Jorge Teixeira, (13) Presidente Médici, and (14) Ministro Andreazza, in the state of Rondônia, and (16) Aripuanã, in the state of Mato Grosso. The figure also shows federal road BR-364 and regions within 12.5 km of this road (projection UTM).

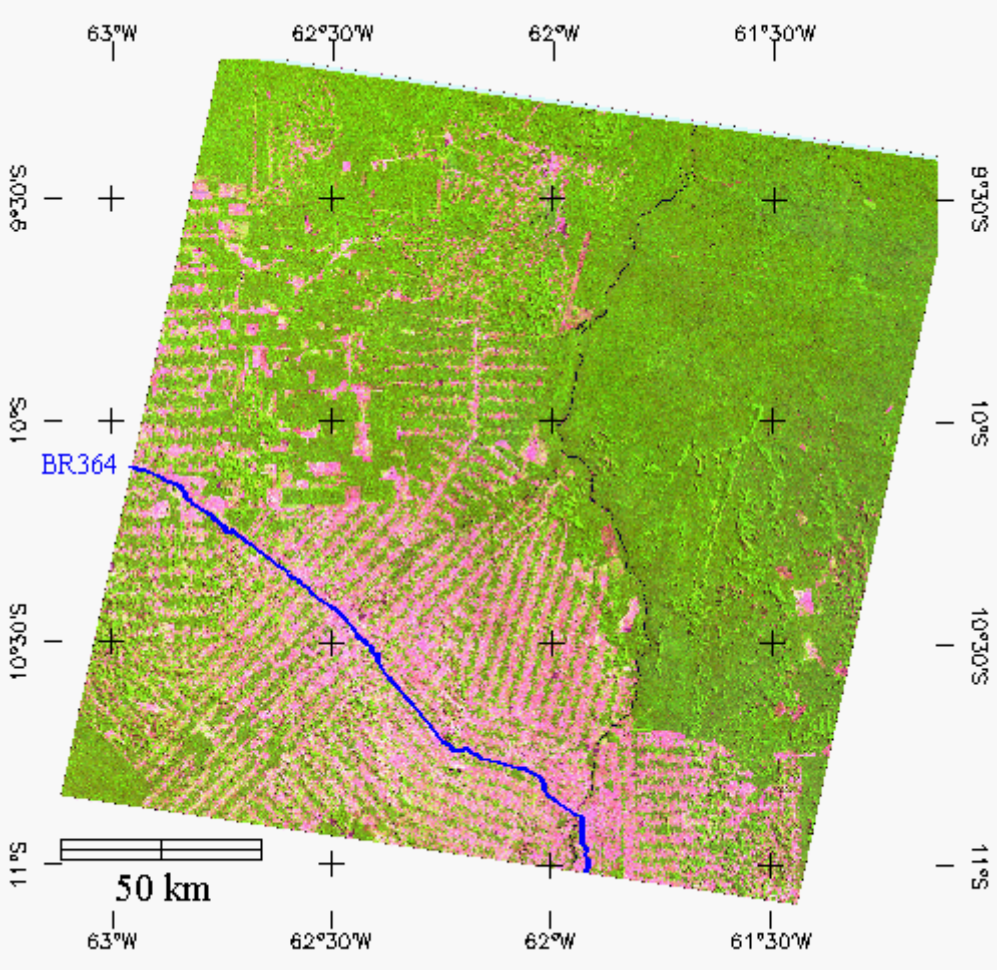

Figure 2 - Color composite of the image used in the study (TM5 - Red; TM4 - Green; TM3 - Blue). Deforested areas are predominantly pink, while forest appears in green. Also shown - federal road BR364. Date of the image - 03 August 1995. Projection - UTM.

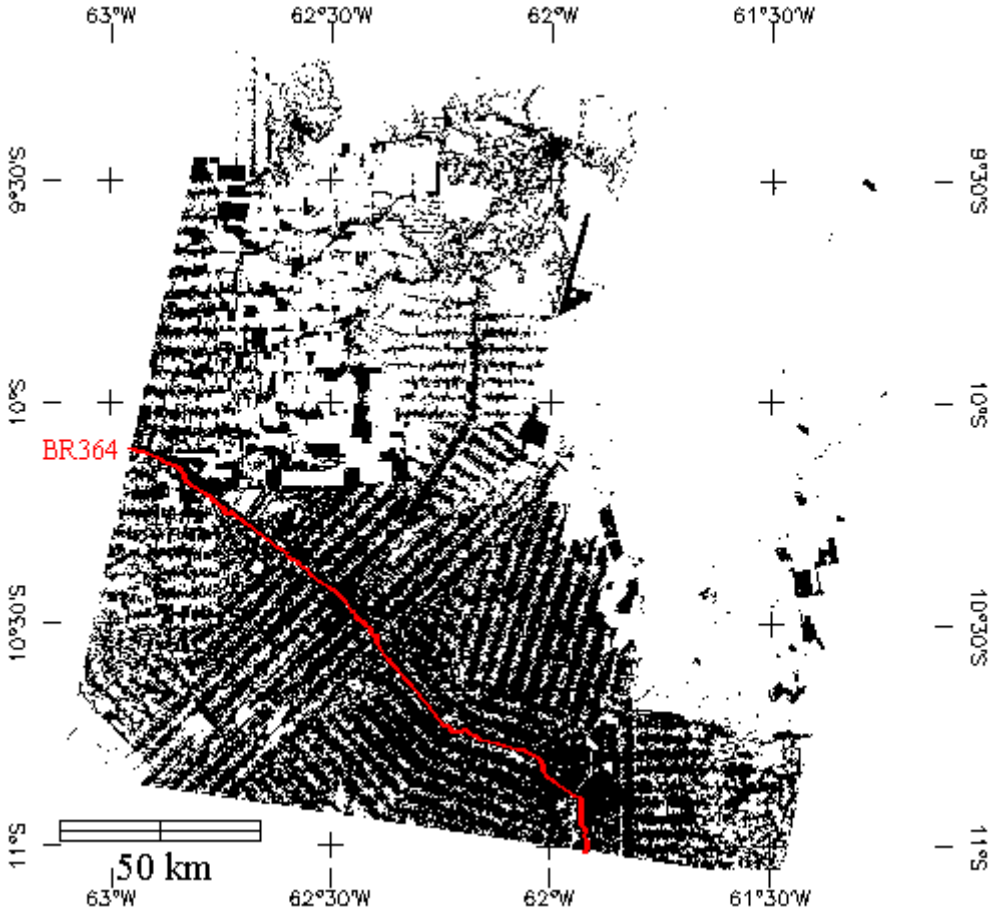

Figure 3 - Deforested area (in black) by 03 August inside the study region. The more compact occupation in regions close to the BR364 road is noticed in the figure. The fishbone pattern typical of Rondônia can also be seen in several parts of the map. Some large isolated cattle ranches can also be seen. Projection UTM.

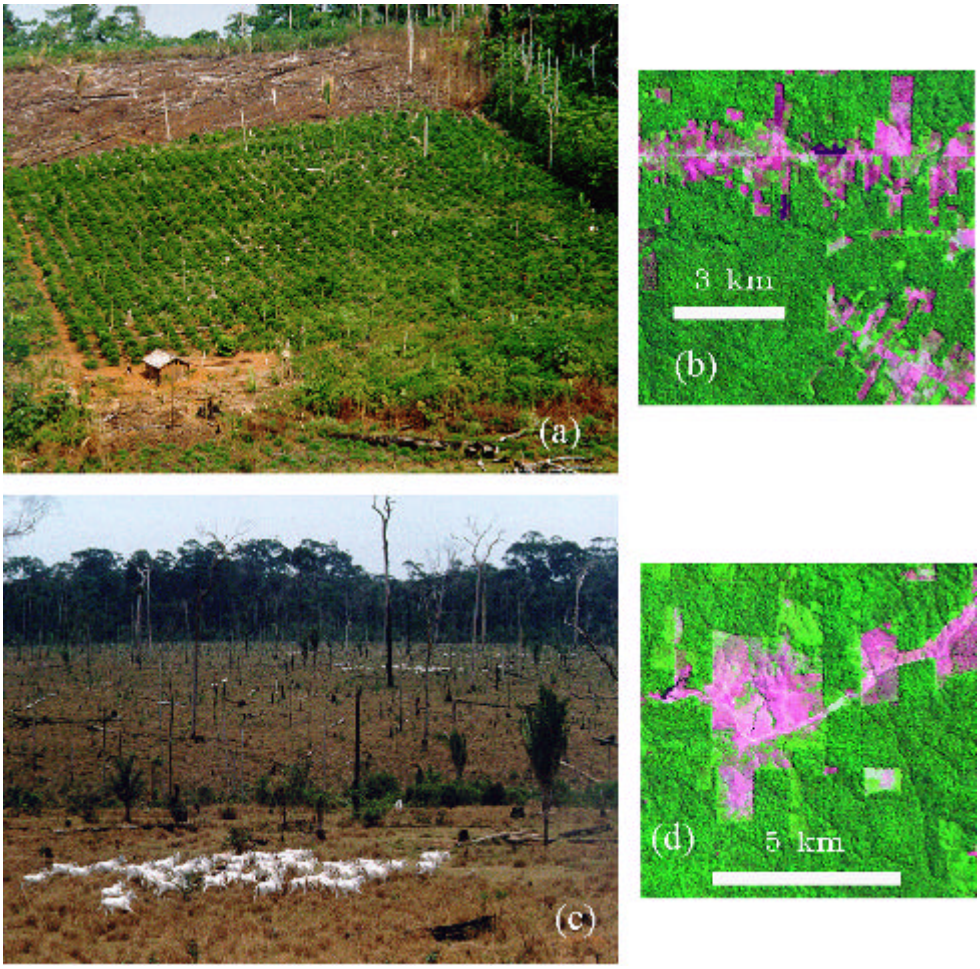

Figure 4 - Views of the land use patterns in the region: coffee plantation in a new settlement project (a) and pastures (c), and corresponding patterns on TM color composites (respectively (b) and (d)). Older settlement projects present few remaining forest and are frequently converted to pastures in the study area.